Preschool Mathematics and Literacy Skills and Educational Attainment in Adolescents Born Preterm and Full Term

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Objectives To test whether preschool academic skills were associated with educational attainment in adolescence and whether associations differed between individuals born preterm and at full term.

Study design This prospective cohort study comprised 6924 individuals, including n = 444 (6.4%) adolescents born preterm (<37 weeks of gestation) from the Avon Longitudinal Study of Parents and Children. Preschool academic (mathematics and literacy) skills were rated by teachers at 4-5 years. Educational attainment at 16 years was informed by attaining a General Certificate of Secondary Education (GCSE) in key subjects mathematics and English. Logistic regressions assessed the association between preterm birth, preschool mathematics, and GCSE Mathematics and between preterm birth, preschool literacy, and GCSE English.

Results Similar numbers of adolescents born preterm and at term achieved a GCSE in mathematics and English (53.6 % vs 57.4% and 59.5% vs 63.9%, respectively; *P* values > .05). Higher preschool academic skill scores in mathematics were associated with greater odds of attaining GCSE Mathematics and preschool literacy skills were associated with GCSE English. Adolescents born preterm with higher preschool mathematics (OR: 1.51, CI: 1.14, 2.00) and literacy skills (OR: 1.57, CI: 1.10, 2.25) were more likely to attain GCSEs in the respective subject than their term-born counterparts with equal levels of preschool skills.

Conclusions Preschool academic skills in mathematics and literacy are associated with educational attainment of preterm and term-born individuals in adolescence. Children born prematurely may benefit more from preschool mathematics and literacy skills for academic and educational success into adolescence than term-born individuals. *(J Pediatr 2024;264:113731)*.

Mathematical and reading difficulties in childhood can have far-reaching consequences into adult life and negatively influence educational attainment, earnings, wealth, and health.[1-5] Compared with their term-born peers, children born preterm (<37 weeks of gestation) are at an increased risk for learning difficulties and poorer academic attainment at school age, particularly in domains such as mathematics and reading.[6-15] Children born preterm and especially those born before 32 weeks of gestation are at increased risk for general cognitive difficulties that can co-occur with other neuropsychological processes, including executive function, attention, visual-spatial skills, and working memory, which have all been shown to be associated with learning difficulties in both mathematics and reading.[10,16-21] Given the rising number of preterm births,[22] there is an increasing need to provide education professionals with information and guidance allowing them to adequately support children born preterm in their educational and academic needs.[23]

The years before formal schooling are important in a child's development. Early identification of academic weaknesses before formal schooling and early educational programs, and early intervention can positively affect children's cognitive and socio-emotional skills that are important for their medium to long-term educational achievement and life outcomes.[24,25] This is particularly true for those from disadvantaged backgrounds.[26-33] There is evidence that school readiness and better early academic skills are associated with improvements in later academic and educational outcomes as well as with economic and societal advancement.[25,33,34] However, studies that investigate the

ALSPAC	Avon Longitudinal Study of Parents and Children
GCSE	General Certificate of Secondary Education

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long-term associations between preschool academic skills and adolescent educational achievement in preterm populations are scarce.

Although preterm-born children have an elevated risk for learning problems and are less likely to achieve good grades in school compared with term-born peers, we hypothesized that good preschool mathematics and literacy skills would be associated with educational success in adolescence. The aim of this study was to investigate whether preschool academic skills, in mathematics and literacy, were associated with decreased risks of preterm birth on educational attainment in adolescence, and to test whether associations between preschool academic skills and later educational attainment differ between preterm and term-born individuals. The study utilized data from a large nationally representative prospective cohort study in the United Kingdom with data on preterm birth status (ie, gestational age), and with record linkage data on preschool mathematics and literacy abilities, and educational attainment in adolescence (ie, the General Certificate of Secondary Education [GCSE]).

Methods

Sample and Participants

The current study used data from a large prospective longitudinal study, the Avon Longitudinal Study of Parents and Children (ALSPAC).[35,36] ALSPAC is a birth cohort in the United Kingdom and examines the determinants of development and health across the life course. Details of the study are described elsewhere.[35,36] ALSPAC recruited 14 541 pregnant women with expected delivery dates of April 1, 1991-December 31, 1992. Of the initial pregnancies, there were 14 676 fetuses resulting in 14 062 live births; 13 988 children were alive at 1 year of age.[35,36]

Ethical approval was obtained from the ALSPAC Ethics and Law committee and the Local Research Ethics Committees (NHS Haydock REC: 10/H1010/70). Informed consent for the use of data collected via questionnaires and clinics was obtained from participants following the recommendations of the ALSPAC Ethics and Law Committee at the time. From the first trimester of pregnancy, parents completed postal questionnaires about themselves and the study child. Children were invited to annual assessment clinics, including face-to-face interviews, and psychological and physical tests from 7 years onward. At age 18, study children were sent 'fair processing' materials describing ALSPAC's intended use of their health and administrative records and were given clear means to consent or object via a written form. Data were not extracted for participants who objected, or who were not sent fair processing materials. The study website contains details of all data available through a fully searchable data dictionary and variable search tool (http://www.bristol.ac.uk/alspac/researchers/our-data/).

Measures

Variables of Interest. Preterm birth: Information on gestational age was based on maternal reports of the last menstrual period. Preterm birth was defined as birth at less than 37 weeks of gestation.

Preschool academic skills: Teachers rated children's preschool academic skills in the first half of their first term in reception class, at age 4 to 5 years. Children were rated on a scale from two to seven on mathematics, reading and writing abilities, with higher scores indicating better skills. Scores for ALSPAC participants were obtained through parent-consented record linkage which were available for 68% of children alive at 1 year of age.[37] For the current study reading and writing scales were combined into a mean literacy score.

Educational attainment: In the UK, the GCSE is the main qualification taken by most pupils at age 16 years when they complete the first stage of secondary school education (Key Stage 4). Data were obtained through linkage to the National Pupil Database (NPD) for England and were identified for 84% of children alive at 1 year.[37] The GCSE examinations include mathematics, English and additional subjects.[38,39] Information on whether an adolescent achieved a passing grade (A*-C) on the GCSE in mathematics and English was coded: 0 = no and 1 = yes, respectively.

Longitudinal data on all variables of interest were available for n = 6924 participants (see Figure 1).

Covariates. Based on their association with the variables of interest (ie, either preterm birth, early academic skills, or educational attainment), several covariates were considered (Shown in Table I).[44-46] These included both child and

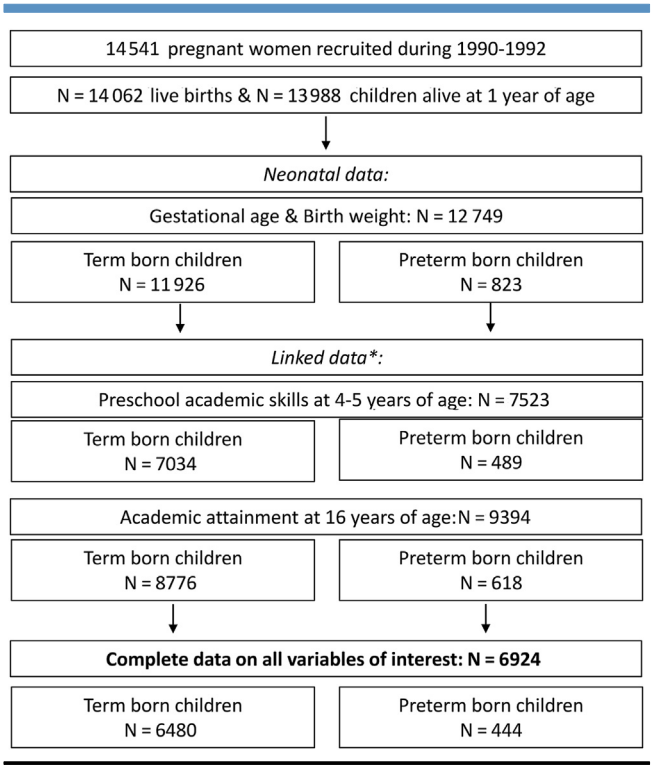

Figure 1. ALSPAC flow chart (*linked preschool and school data were available for 68% and 84% of children alive at 1 year of age, respectively).

Table I. Sample characteristics (n = 6924)

Variable	N	Term n = 6480 (93.6%) Mean (SD) or %	Preterm n = 444 (6.4%) Mean (SD) or %	*P* value
Neonatal/neurosensory variables				
Gestational age, wk, mean (SD)	6924	39.52 (1.16)	34.40 (2.30)	<.001
Preterm birth groups, wk of gestation (%)	6924			*n/a*
Extremely preterm <28		-	3.2	
Very preterm 28-31		-	7.4	
Moderate to late preterm 32-36		-	89.4	
Early term 37-38		20.0	-	
Full term 39-41		80.0	-	
Birth weight, mean (SD)	6916	3436 (484)	2403 (627)	<.001
Sex (male), %	6924	49.9	57.7	.001
Predictors at preschool age				
Preschool academic skills at 4-5 y, mean (SD)				
Mathematics	6924	5.30 (1.09)	5.01 (1.04)	<.001
Literacy	6924	4.99 (0.78)	4.86 (0.79)	<.001
Outcomes in adolescence				
Educational achievement (GCSE achieved) at 16 y, %				
Mathematics	6924	57.4	53.6	.12
English	6924	63.9	59.5	.06
Covariates—children				
At age 18 mo				
Developmental score, mean (SD)	5672	81.67 (10.30)	75.46 (11.89)	<.001
Health status, %	5646			.070
Healthy no problems		45.6	42.6	
Few minor problems		49.5	50.0	
Sometimes ill		4.2	5.7	
Hardly ever well		0.7	1.7	
Number of books owned by the child, %	5677			.001
None		1.0	0.3	
1-2 books		4.4	8.5	
3-9 books		29.6	32.4	
>10 books		65.0	58.8	
At age 38 mo				
Cognitive function, mean (SD)				
Intelligibility score	5196	5.62 (0.86)	5.51 (0.89)	.029
Communicative score	5191	5.22 (1.08)	5.35 (1.16)	.032
At age 42 mo				
Emotional difficulties, mean (SD)	5179	2.55 (1.73)	2.61 (1.84)	.48
Conduct difficulties, mean (SD)	5179	3.63 (2.34)	3.70 (2.44)	.64
Hyperactivity, mean (SD)	5179	2.63 (1.79)	2.82 (1.84)	.08
Prosocial, mean (SD)	5179	15.36 (3.52)	14.85 (3.64)	.014
At age 8 y				
Fluid IQ (WISC), mean (SD)	3572	91.31 (24.50)	88.69 (24.86)	.12
Covariates—parents				
Maternal age, mean (SD)	6003	28.08 (4.71)	27.85 (4.64)	.37
Paternal age, mean (SD)	4035	30.70 (5.69)	29.66 (4.79)	.007
Maternal mental health, mean (SD)	5951	5.99 (4.72)	6.30 (5.31)	.24
Maternal smoking during pregnancy, %	6013	20.2	21.7	.50
Breastfeeding, %	5650			.013
Never		26.9	34.9	
<1 mo		17.6	17.4	
1 ≤ 3 mo		16.3	15.4	
3 ≤ 6 mo		12.2	11.7	
>6 mo		26.9	20.6	
Marital status, %	4964			.55
Never married		11.5	10.7	
Widowed		0.3	0.0	
Divorced		5.3	3.9	
Separated		2.7	2.6	
Married once		72.3	72.5	
Marriage 2 or 3		8.0	10.4	
Educational attainment mother, %	5828			.009
Certificate of Secondary Education (CSE)		16.1	22.4	
Vocational		11.6	12.6	
O level		40.5	32.4	
A level		22.6	23.5	
Degree		9.3	9.2	

(*continued*)

Table I. Continued

Variable	N	Term n = 6480 (93.6%) Mean (SD) or %	Preterm n = 444 (6.4%) Mean (SD) or %	*P* value
Educational attainment father, %	5995			.41
Certificate of Secondary Education (CSE)		28.5	31.5	
Vocational		9.7	9.4	
O level		22.8	22.4	
A level		26.5	27.4	
Degree		12.6	9.4	
Employment status mother, %	4829			.044
Employer		0.6	2.1	
Self-employed, no employee		4.8	3.5	
Manager		5.9	5.6	
Supervisor		19.5	19.4	
Other employee		69.3	69.4	
Employment status father, %	5220			.19
Employer		4.0	3.2	
Self-employed, no employee		14.0	15.8	
Manager		11.4	9.7	
Supervisor		24.0	29.0	
Other employee		46.7	42.3	
Social status mother, %	4829			.90
I—Professional		2.5	1.7	
II—Managerial and technical		27.9	28.1	
IIINM—Skilled nonmanual		45.9	46.2	
IIIM—Skilled manual		10.4	9.0	
IV—Partly skilled		10.7	11.8	
V—Unskilled		2.7	3.1	
Social status father, %	5220			.004
I—Professional		6.0	3.9	
II—Managerial and technical		27.9	25.2	
IIINM—Skilled nonmanual		12.3	12.3	
IIIM—Skilled manual		42.8	52.9	
IV—Partly skilled		7.9	4.2	
V—Unskilled		3.2	1.6	

WISC, Wechsler Intelligence Scale for Children.
Child-related variables: child health and developmental status at 18 mo (derived from the Denver Developmental Screening Test[40]), books owned by the child at 18 mo, child's cognitive function (intelligibility, communication; developed and adapted by the ALSPAC study team) at 38 mo, child emotional, hyperactivity and conduct difficulties and prosocial behavior at 42 mo (derived from the Revised Rutter Parent Scale for Preschool Children[41]), and child intelligence at 8 y (Wechsler Intelligence Scale for Children, WISC-III[42]); Parent-related and social-environmental variables: breast-feeding, maternal and paternal age, maternal mental health (Edinburgh Postnatal Depression Scale[43]), marital status, maternal and paternal educational attainment, employment status, and social status (social status is a measure of social class, defined using the UK Registrar General's occupational coding[37]).

parent-related as well as social-environmental covariates. Group differences for all covariates are presented in Table I.

Statistical Analysis

All analyses were conducted in Stata 16 (StataCorp LLC). Group differences were tested with χ^2 tests for categorical variables and *t* tests for continuous variables.

Associations between preschool academic skills and GCSEs were tested using 2 separate logistic regression analyses: A) preschool mathematics skills and GCSE Mathematics and B) preschool literacy skills and GCSE English. First, we tested associations between preschool academic skills and GCSEs within preterm and term-born participants, separately. Second, we applied stepwise hierarchical logistic regression models to examine whether educational attainment (ie, GCSEs in mathematics and English) was explained by preterm birth and preschool academic skills (ie, mathematics and literacy) (Model 1). To test whether the effect of preschool academic skills on achieved GCSEs was different between preterm and term-born adolescents, an interaction term 'preterm birth by preschool academic skills' was added to each of the 2 models A and B (Model 2). In a final step, both regression models were adjusted for all covariates.

Sensitivity Analyses. We carried out 3 sets of sensitivity analyses. First, logistic regression models were repeated excluding participants with neurosensory (ie, visual, hearing, or learning [IQ < 3 SD]) impairments (n = 41). Second, given that mathematics and literacy skills have been found to be correlated,[5,25] we repeated the main regression models for GCSE Mathematics and English and included both preschool mathematics and literacy skills in each of the model. And third, as only 68% preschool and 84% school data were linked to the ALSPAC sample data, we carried out attrition analyses and performed multiple data imputation by chained equation. Based on the sample with neonatal data (ie, gestational age and birth weight) available for children alive at age 1 year (n = 12 749; **Figure 1**), missing data were imputed on the outcomes (GCSE Mathematics and English), main predictors (preschool mathematics and literacy skills) and covariates.

Results

Sample Characteristics

The group differences for the main predictors and outcome variables are presented in Table I. As per the definition, preterm-born participants had lower gestational ages and birth weights ($P < .001$) than full term participants. There were group differences in the distribution for sex, with preterm-born adolescents being more often of male sex ($P = .001$). Compared with their term-born counterparts, preterm-born adolescents had lower preschool academic skill scores (all $P < .001$). Similarly, the percentage of adolescents born preterm that achieved GCSEs was slightly lower than in term-born adolescents but did not reach statistical significance ($P = .06$-0.16 for mathematics and English, respectively).

In terms of covariates (Table I), preterm-born children had a lower developmental score ($P < .001$) and owned fewer books ($P = .001$) at age 18 months. At age 38 months, children born preterm had a lower language intelligibility score ($P = .029$) but a higher communicative score ($P = .032$), and at age 42 months a lower prosocial score ($P = .014$) compared with term-born children. Regarding social-environmental covariates, children born preterm were less likely to have been breastfed ($P = .013$). Furthermore, compared with parents of term-born children, fathers of children born preterm were younger ($P = .007$) and had a lower social status ($P = .004$), and mothers had achieved a lower educational attainment ($P = .009$).

Associations between Preterm Birth, Preschool Academic Skills, and Educational Attainment

The results of the stepwise logistic regression analyses for both models, that is, preschool mathematics skills and attainment of GCSE Mathematics, and preschool literacy skills and attainment of GCSE English, are presented in Table II.

Preterm Birth, Preschool Mathematics, and (A*-C) GCSE Mathematics. Model 1 shows that preterm birth was not associated with the attainment of a GCSE (short for A*-C GCSE) in Mathematics (OR: 1.07, 95% CI: 0.88, 1.31) in adolescence. However, all individuals with a higher preschool mathematics scores were twice as likely to attain a GCSE in mathematics (OR: 2.30, 95% CI: 2.18, 2.43) compared with adolescents with lower preschool skill scores. Adding the interaction term 'preterm birth by preschool mathematics skills' showed that children born preterm who achieved higher mathematics skill scores in preschool were more likely to achieve a GCSE in mathematics than term-born adolescents with similar preschool mathematics scores (OR: 1.51, 95% CI: 1.14, 2.00, Table II and Figure 2, panel A). None of these associations changed significantly in adjusted models (Table II). Additional examinations within birth groups showed that term-born adolescents with higher preschool mathematics skills were twice as likely to achieve a GCSE in mathematics (OR: 2.25, CI: 2.13, 2.39). Within individuals born preterm, this association increased to a three-fold higher likelihood (OR: 3.40, 95% CI: 2.58, 4.48).

Preterm Birth, Preschool Literacy, and GCSE English. As with GCSE Mathematics, preterm birth was not associated with GCSE English (OR: 0.95, 95% CI: 0.77, 1.16), but preschool literacy skills were positively associated with a GCSE in English (OR: 3.48, 95% CI: 3.21, 3.77). Again, adding the interaction term 'preterm birth by preschool literacy skills' showed a significant association with GCSE in English (OR: 1.57, 95% CI: 1.10, 2.25), indicating that adolescents born preterm who had higher preschool literacy skill scores had a greater chance of attaining a GCSE in English, compared with term-born peers with equal preschool skill scores (see Figure 2, panel B). All effects remained significant after adjusting for covariates (Table II). Within-group analysis showed that term-born children with higher preschool literacy skills were 3 times more likely to achieve a GCSE in English (OR: 3.39, CI: 3.12, 3.68). In contrast, individuals born preterm were 5 times more likely to achieve a GCSE in English (OR: 5.32, 95% CI: 3.76, 7.53).

Sensitivity Analyses

To assess whether neurosensory impairment influenced the associations between preschool skills, educational attainment in adolescence, and birth status, we omitted participants with neurosensory impairment. The results for both regression models did not change substantially (Table III, available at www.jpeds.com).

As preschool mathematics and literacy skills were correlated ($r = 0.63$, $P < .001$), a second set of sensitivity analyses was carried out with both preschool academic skill variables, that is, mathematics and literacy (Table IV, available at www.jpeds.com) included in each of the regression models. Again, the results of the models changed only marginally (Table II).

Finally, the attrition analysis (Table V, available at www.jpeds.com) based on the sample with neonatal data (ie, gestational age and birth weight) available for children alive at age 1 year (n = 12 749; Figure 1) showed that adolescents born preterm who were not included in the complete case analysis were born at lower gestational age and birth weight compared with those included ($P = .008$ and $P = .01$, respectively). In the group of term-born adolescents, males were more likely not to have been included in the complete case analysis ($P = .004$) and term-born adolescents that were lost to attrition were more likely to achieve a GCSE in mathematics and in English, compared with those with complete data ($P < .001$). Repeating the regression models with multiple imputed data (Table VI, available at www.jpeds.com) showed that the main effects of preterm birth and preschool mathematics skills on GCSE Mathematics and preschool literacy on GCSE English were similar in their magnitude compared with the results of the main analyses (Table II). However, while the interaction term 'preterm birth by preschool mathematics skills' remained statistically

Table II. Unadjusted and adjusted* associations between preschool academic skills and GCSEs in adolescence (n = 6924)

	GCSE Mathematics OR (95% CI)		GCSE English OR (95% CI)	
Unadjusted models	**Model 1**	**Model 2**	**Model 1**	**Model 2**
Preterm birth	1.07 (0.88, 1.31)	0.14‡ (0.04, 0.57)	0.95 (0.77, 1.16)	0.11† (0.02, 0.61)
Preschool mathematics skills	2.30§ (2.18, 2.43)	2.25§ (2.13, 2.39)	-	-
Interaction preterm birth by preschool mathematics skills	-	1.51‡ (1.14, 2.00)	-	-
Preschool literacy skills	-	-	3.48§ (3.21, 3.77)	3.39§ (3.12, 3.68)
Interaction preterm birth by preschool literacy skills	-	-	-	1.57† (1.10, 2.25)
Pseudo R^2	0.117	0.119	0.128	0.129
Adjusted* models	**Model 1**	**Model 2**	**Model 1**	**Model 2**
Preterm birth	1.15 (0.92, 1.44)	0.19† (0.05, 0.83)	1.16 (0.92, 1.47)	0.09† (0.01, 0.64)
Preschool mathematics skills	1.83§ (1.72, 1.95)	1.80§ (1.69, 1.92)	-	-
Interaction preterm birth by preschool mathematics skills	-	1.43† (1.07, 1.93)	-	-
Preschool literacy skills	-	-	2.38§ (2.17, 2.61)	2.30§ (2.10, 2.53)
Interaction preterm birth by preschool literacy skills	-	-	-	1.73‡ (1.14, 2.63)
Pseudo R^2	0.232	0.233	0.260	0.260

*Adjusted for all covariates (child-related variables: child sex, child health and developmental status at 18 mo, books owned by the child at 18 mo, child's cognitive function [intelligibility, communication] at 38 mo, child emotional, hyperactivity and conduct difficulties and prosocial behavior at 42 mo, and child intelligence at 8 y; parent-related and social-environmental variables: breastfeeding, maternal and paternal age, maternal mental health, marital status, maternal and paternal educational attainment, employment status, and social status).
†$P < .05$.
‡$P < .01$.
§$P < .001$.

significant in the unadjusted model (OR: 1.28, 95% CI: 1.00, 1.64), it was no longer significant after adjusting for covariates (OR: 1.25, 95% CI: 0.99, 1.59). In contrast, the interaction term 'preterm birth by preschool literacy skills' was not significantly associated with GCSE English, neither in the unadjusted (OR: 1.30, 95% CI: 0.84, 2.00) nor in the adjusted model (OR: 1.36, 95% CI: 0.79, 2.35).

Discussion

The findings of this study show that higher levels of preschool mathematics and literacy skills are associated with an improved likelihood of achieving educational qualifications (ie, GCSEs in mathematics and English) in adolescence. Preterm birth was associated with lower preschool academic skills in mathematics and literacy but not with educational achievement at 16 years. Although preterm birth was not directly associated with educational attainment in adolescence, the findings of the current study demonstrate that children born preterm with higher preschool academic skill scores are more likely to achieve GCSEs in mathematics and English than term-born individuals with the same level of preschool skills. Notably, these associations were independent of important covariates, including family socioeconomic status and child intelligence.

In accordance with previous work, the findings of this study demonstrate that preschool academic skills such as early mathematics and literacy skills have long-lasting benefits for educational attainment and academic success.[27,29] Confirming the findings of previous work,[6,8,11,12] the current

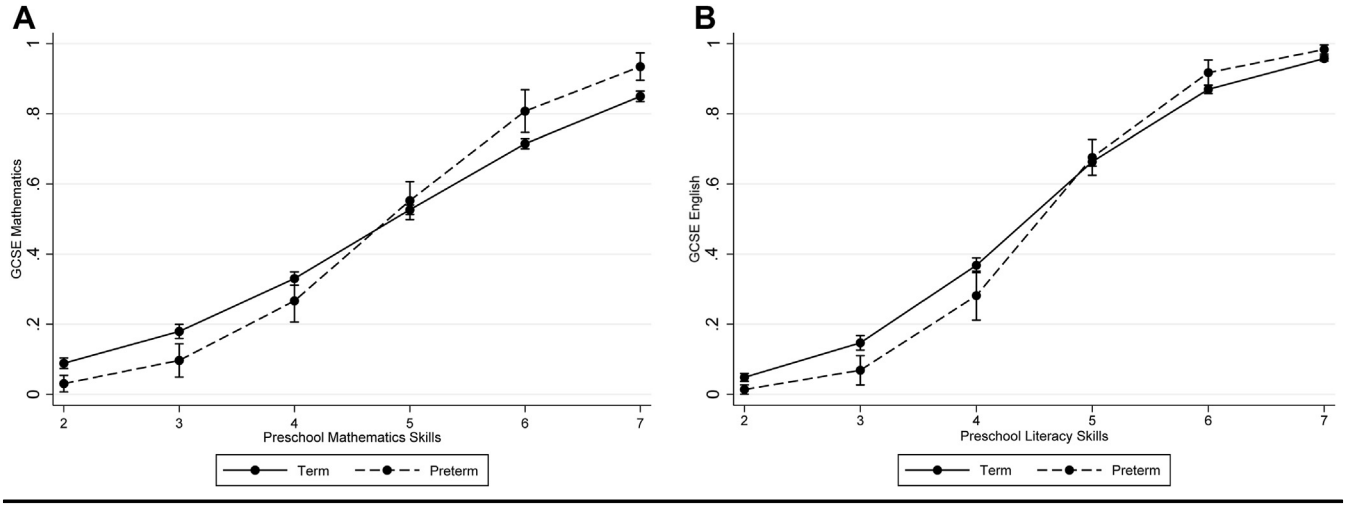

Figure 2. A, Interaction 'preterm birth by preschool mathematics skills' on GCSE Mathematics and **B,** interaction 'preterm birth by preschool literacy skills' on GCSE English (adjusted prediction with 95% CI).

study showed that prematurity is associated with preschool academic skills, though an association between prematurity and educational achievement in adolescence could not be replicated. However, importantly, the current study detected a positive association between the interaction term 'preterm birth by preschool skill' and educational attainment. This suggests that compared with their term-born counterparts, individuals born preterm with higher levels of early academic skills in mathematics and literacy were more likely to accomplish important educational qualifications in adolescence. In other words, adolescents born preterm who accomplish higher levels of preschool skills benefitted disproportionately in regard to later educational attainment, compared with term-born individuals who have achieved equal levels of preschool academic skills. This may suggest that children born preterm may be more sensitive to positive environmental influences such as preschool education than those born term as proposed by theories of differential susceptibility or vantage sensitivity.[47-49] Considering this finding, it may be speculated that individuals born very preterm might benefit equally or more from higher preschool academic skills compared with moderate to late preterm and term-born adolescents. However, we could not explore this possibility due to the small number of very preterm-born participants in the current study (n = 47). Further, it is important to note that the magnitude of the tested associations did not change when we included mathematics and literacy in the same model as a sensitivity analysis. This suggests that both mathematics and literacy skills seem to be important core subjects for academic attainment of children born preterm.

Prior evidence suggests that children born preterm not only have more academic difficulties than their term-born peers,[6,24] but these difficulties also seem to persist into employment in adulthood.[11,50,51] Therefore, early learning programs that are tailored to the educational needs of children born preterm may be important in ensuring their academic success. Together with the rising number of children born preterm worldwide[22] and the widening gap between preterm and term-born children in their academic performance over the past 2 decades,[52] fostering early academic skills of children born preterm, in particular mathematics and literacy skills, may be an important strategy to support these children and their families and enhance long-term educational success and life chances of children born preterm.[53]

The findings of this study may be of particular interest to parents, education professionals, and policy makers regarding the learning needs of children born preterm. Further, the findings may inform planning and setting up effective preschool programs. Early education and preschool programs for children born preterm may enhance learning in core school subjects and developmental outcomes, foster social participation, and improve their academic and educational proficiency. These may positively influence later well-being and success in education and employment.[31,54] However, it is not just the provision of preschool or early learning programs that matter. Attendance, duration, and the quality of preschool education have been found to be important factors that can influence the impact of early learning and education on children's later academic outcomes.[31] Other social environmental factors that directly or indirectly affect early learning, academic performance and education are parent education and socioeconomic status, the home learning environment, cognitive and noncognitive stimulation, and parenting behavior.[33,55-62] In addition to these social environmental provisions, it is important to foster motivation, interest, and enjoyment in early learning as this can influence later learning, educational achievement and wealth, independent of cognitive ability.[33,63] More research is needed to identify specific environmental and medical factors and to understand the role and association of these factors with early academic skills and medium to long-term educational achievement in children born preterm.

The strengths of this study are its longitudinal design and large sample that included children born across the full spectrum of gestational age. The study further provided a wide range of important measures and covariates representing family socioeconomic status and environment as well as children's mental and physical health, behavior, and cognitive ability across different ages from preschool to school age. However, there are also limitations. Information on provisions of educational support and intervention programs were lacking. Although home environment factors, such as social activities or activities that may provide learning opportunities,[64] were not available in the present study, many variables that capture family socioeconomic status (ie, parents' educational attainment, employment, and social status) as well as aspects of the home environment (eg, number of books owned by the child) were considered. Further, despite the demonstrated links between preschool skills, prematurity, and educational attainment, a causal relationship cannot be confirmed in this prospective cohort study. Therefore, residual confounding may still be possible, for example, through other environmental and social factors that may affect preschool skills or academic success and that were not included in the current study, such as parental support or maternal sensitivity.[47,57] Further, preschool skills were rated by teachers, and scores may therefore include assessor bias. In addition, despite the large sample size available for this study attrition cannot be avoided in a longitudinal study. The current study was reliant on linkage data provided by schools and the National Pupil Database for England providing preschool academic skills and GCSE data for 68% and 84% of ALSPAC children alive at 1 year of age. Thus, attrition was substantial and our attrition analysis (**Table V**, available at www.jpeds.com) showed a significant difference in achieved GCSEs between term-born adolescents included and excluded in the complete data analysis, that is, more term-born adolescents without complete data achieved GCSEs in mathematics and English. It may therefore be possible that the associations between preschool academic skills and achieved GCSEs have been underestimated in the term group which in turn may mean

that the beneficial effect of preschool skills is more equal between preterm and term-born children.

Furthermore, ALSPAC includes children born between 1991 and 1992. Changes in reproductive medicine and improvements in neonatal care over the last decades have led to increased survival rates for babies born preterm with larger numbers in the community. However, despite these improvements, rates of neurodevelopmental difficulties, including academic and educational difficulties, remain significantly higher compared with term-born peers, in contemporary cohorts.[52,65,66] As a result, the need for educational support for children born preterm remains high.

Overall, our results not only suggest that attending preschool and doing well in subjects such as mathematics and literacy is important for later educational attainment for all children but that the mastery of early academic skills may be particularly important for the educational success of children born preterm, over and above other important developmental, cognitive, behavioral, and social-environmental influences. The findings of the current study therefore underpin and extend previous work in advocating the provision of high-quality early education with the aim to foster and improve children's early developmental progress and academic proficiency, and to reduce special educational needs and economic burden, for disadvantaged and preterm-born children.[28,30,31,33]

Preschool academic skills are positively associated with long-term academic achievement. Preterm-born children may benefit disproportionately for their educational success from early learning and preschool programs that promote numeracy and literacy skills. The findings highlight the importance of early learning and preschool programs that foster all children's early academic performance to enhance their long-term educational success. ■

Declaration of Competing Interest

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References

1. Basten M, Jaekel J, Johnson S, Gilmore C, Wolke D. Preterm birth and adult wealth: mathematics skills count. Psychol Sci 2015;26:1608-19.
2. Nomura Y, Halperin JM, Newcorn JH, Davey C, Fifer WP, Savitz DA, et al. The risk for impaired learning-related abilities in childhood and educational attainment among adults born near-term. J Pediatr Psychol 2009;34:406-18.
3. Feinstein L, Sabates R, Anderson TM, Sorhaindo A, Hammond C. What are the effects of education on health? In: Desjardins R, Schuller T, eds. Measuring the effects of education on health and civic engagement: proceedings of the Copenhagen Symposium. Paris: OECD; 2006. p. 171-353.
4. Organisation for Economic Co-operation and Development (OECD). Health at a Glance 2017. Paris: OECD Indicators; 2019.
5. Crawford C, Cribb J. Reading and maths skills at age 10 and earnings in later life: a brief analysis using the British cohort study. UK: Centre for Analysis of Youth Transitions (CAYT); 2013.
6. McBryde M, Fitzallen GC, Liley HG, Taylor HG, Bora S. Academic outcomes of school-aged children born preterm: a systematic review and meta-analysis. JAMA Netw Open 2020;3:e202027.
7. Martínez-Nadal S, Bosch L. Cognitive and learning outcomes in late preterm infants at school age: a systematic review. Int J Environ Res Public Health 2020;18:74.
8. de Jong M, Verhoeven M, van Baar AL. School outcome, cognitive functioning, and behaviour problems in moderate and late preterm children and adults: a review. Semin Fetal Neonatal Med 2012;17:163-9.
9. Quigley MA, Poulsen G, Boyle E, Wolke D, Field D, Alfirevic Z, et al. Early term and late preterm birth are associated with poorer school performance at age 5 years: a cohort study. Arch Dis Child Fetal Neonatal Ed 2012;97:F167-73.
10. Simms V, Cragg L, Gilmore C, Marlow N, Johnson S. Mathematics difficulties in children born very preterm: current research and future directions. Arch Dis Child Fetal Neonatal Ed 2013;98:F457-63.
11. Allotey J, Zamora J, Cheong-See F, Kalidindi M, Arroyo-Manzano D, Asztalos E, et al. Cognitive, motor, behavioural and academic performances of children born preterm: a meta-analysis and systematic review involving 64 061 children. BJOG 2018;125:16-25.
12. Twilhaar ES, de Kieviet JF, Aarnoudse-Moens CS, van Elburg RM, Oosterlaan J. Academic performance of children born preterm: a meta-analysis and meta-regression. Arch Dis Child Fetal Neonatal Ed 2018;103:F322-30.
13. Trickett J, Gilmore C, Cragg L, Clayton S, Marlow N, Simms V, et al. No excess of mathematics anxiety in adolescents born very preterm. J Dev Behav Pediatr 2021;42:220-6.
14. O'Nions E, Wolke D, Johnson S, Kennedy E. Preterm birth: educational and mental health outcomes. Clin Child Psychol Psychiatry 2021;26:750-9.
15. Aarnoudse-Moens CS, Weisglas-Kuperus N, van Goudoever JB, Oosterlaan J. Meta-analysis of neurobehavioral outcomes in very preterm and/or very low birth weight children. Pediatrics 2009;124:717-28.
16. Johnson S, Strauss V, Gilmore C, Jaekel J, Marlow N, Wolke D. Learning disabilities among extremely preterm children without neurosensory impairment: comorbidity, neuropsychological profiles and scholastic outcomes. Early Hum Dev 2016;103:69-75.
17. Trickett J, Bernardi M, Fahy A, Lancaster R, Larsen J, Ni Y, et al. Neuropsychological abilities underpinning academic attainment in children born extremely preterm. Child Neuropsychol 2022;28:746-67.
18. Twilhaar ES, De Kieviet JF, Van Elburg RM, Oosterlaan J. Neurocognitive processes underlying academic difficulties in very preterm born adolescents. Child Neuropsychol 2020;26:274-87.

19. Mulder H, Pitchford NJ, Marlow N. Processing speed and working memory underlie academic attainment in very preterm children. Arch Dis Child Fetal Neonatal Ed 2010;95:F267-72.
20. Allen K, Higgins S, Adams J. The relationship between visuospatial working memory and mathematical performance in school-aged children: a systematic review. Educ Psychol Rev 2019;31:509-31.
21. Johnson S, Wolke D, Hennessy E, Marlow N. Educational outcomes in extremely preterm children: neuropsychological correlates and predictors of attainment. Dev Neuropsychol 2011;36:74-95.
22. Chawanpaiboon S, Vogel JP, Moller AB, Lumbiganon P, Petzold M, Hogan D, et al. Global, regional, and national estimates of levels of preterm birth in 2014: a systematic review and modelling analysis. Lancet Glob Health 2019;7:e37-46.
23. Johnson S, Gilmore C, Gallimore I, Jaekel J, Wolke D. The long term consequences of preterm birth: what do teachers know? Dev Med Child Neurol 2015;57:571-7.
24. Hasler HM, Akshoomoff N. Mathematics ability and related skills in preschoolers born very preterm. Child Neuropsychol 2019;25:162-78.
25. Duncan GJ, Dowsett CJ, Claessens A, Magnuson K, Huston AC, Klebanov P, et al. School readiness and later achievement. Dev Psychol 2007;43:1428-46.
26. McCormick MC, Brooks-Gunn J, Buka SL, Goldman J, Yu J, Salganik M, et al. Early intervention in low birth weight premature infants: results at 18 years of age for the Infant Health and Development Program. Pediatrics 2006;117:771-80.
27. Heckman J, Pinto R, Savelyev P. Understanding the mechanisms through which an influential early childhood program boosted adult outcomes. Am Econ Rev 2013;103:2052-86.
28. Sammons P. Does pre-school make a difference? In: Sylva K, Melhuish E, Sammons P, Siraj-Blatchford I, Taggart B, eds. Early childhood matters: evidence from the effective Pre-school and Primary Education Project. London, United Kingdom: Taylor & Francis Group; 2010.
29. Sammons P. Do the benefits of pre-school last? Investigating pupil outcomes to the end of Key Stage 2 (aged 11). In: Sylva K, Melhuish E, Sammons P, Siraj-Blatchford I, Taggart B, eds. Early childhood matters : evidence from the effective Pre-school and Primary Education Project. London, United Kingdom: Taylor & Francis Group; 2010.
30. Melhuish EC. Education. Preschool matters. Science 2011;333:299-300.
31. Organisation for Economic Co-operation and Development (OECD). Early learning matters. 2018. Accessed May 6, 2022. https://www.oecd.org/education/school/Early-Learning-Matters-Project-Brochure.pdf?_ga=2.23007357.775815441.1651811191-1186738298.1651811191
32. Currie J. Early childhood education programs. J Econ Perspect 2001;15:213-38.
33. Heckman JJ. Skill formation and the economics of investing in disadvantaged children. Science 2006;312:1900-2.
34. Romano E, Babchishin L, Pagani LS, Kohen D. School readiness and later achievement: replication and extension using a nationwide Canadian survey. Dev Psychol 2010;46:995-1007.
35. Boyd A, Golding J, Macleod J, Lawlor DA, Fraser A, Henderson J, et al. Cohort profile: the 'children of the 90s'–the index offspring of the Avon Longitudinal Study of Parents and Children. Int J Epidemiol 2013;42:111-27.
36. Fraser A, Macdonald-Wallis C, Tilling K, Boyd A, Golding J, Davey Smith G, et al. Cohort profile: the Avon Longitudinal Study of Parents and Children: ALSPAC mothers cohort. Int J Epidemiol 2013;42:97-110.
37. Chittleborough CR, Mittinty MN, Lawlor DA, Lynch JW. Effects of simulated interventions to improve school entry academic skills on socioeconomic inequalities in educational achievement. Child Dev 2014;85:2247-62.
38. Department for Education. Revised GCSE and equivalent results in England, 2015 to 2016. London, United Kingdom: Department for Education; 2017.
39. Department for Education. Revised GCSE and equivalent results in England, 2016 to 2017. Darlington, United Kingdom: Department for Education; 2018.
40. Frankenburg WK, Dodds JB. The Denver developmental screening test. J Pediatr 1967;71:181-91.
41. Elander J, Rutter M. Use and development of the Rutter parents' and teachers' scales. Int J Methods Psychiatr Res 1996;6:63-78.
42. Wechsler D, Golombok S, Rust J. WISC-III UK Wechsler intelligence scale for children. Third UK manual ed. Sidcup, UK: The Psychological Corporation; 1992.
43. Paul E, Pearson RM. Depressive symptoms measured using the Edinburgh Postnatal Depression Scale in mothers and partners in the ALSPAC Study: A data note. Wellcome Open Res 2020;5:108.
44. Alterman N, Johnson S, Carson C, Petrou S, Kurinzcuk JJ, Macfarlane A, et al. Gestational age at birth and academic attainment in primary and secondary school in England: evidence from a national cohort study. PLoS One 2022;17:e0271952.
45. Jeong J, McCoy DC, Fink G. Pathways between paternal and maternal education, caregivers' support for learning, and early child development in 44 low- and middle-income countries. Early Child Res Q 2017;41:136-48.
46. Bornstein MH, Putnick DL. Cognitive and socioemotional caregiving in developing countries. Child Dev 2012;83:46-61.
47. Jaekel J, Pluess M, Belsky J, Wolke D. Effects of maternal sensitivity on low birth weight children's academic achievement: a test of differential susceptibility versus diathesis stress. J Child Psychol Psychiatry 2015;56:693-701.
48. Lionetti F, Aron A, Aron EN, Burns GL, Jagiellowicz J, Pluess M. Dandelions, tulips and orchids: evidence for the existence of low-sensitive, medium-sensitive and high-sensitive individuals. Transl Psychiatry 2018;8:24.
49. Ellis BJ, Boyce WT, Belsky J, Bakermans-Kranenburg MJ, van Ijzendoorn MH. Differential susceptibility to the environment: an evolutionary–neurodevelopmental theory. Dev Psychopathol 2011;23:7-28.
50. Kovachy VN, Adams JN, Tamaresis JS, Feldman HM. Reading abilities in school-aged preterm children: a review and meta-analysis. Dev Med Child Neurol 2015;57:410-9.
51. Twilhaar ES, de Kieviet JF, van Elburg RM, Oosterlaan J. Academic trajectories of very preterm born children at school age. Arch Dis Child Fetal Neonatal Ed 2019;104:F419-f423.
52. Cheong JLY, Anderson PJ, Burnett AC, Roberts G, Davis N, Hickey L, et al. Changing neurodevelopment at 8 Years in children born extremely preterm since the 1990s. Pediatrics 2017;139:e20164086.
53. Jaekel J, Anderson PJ, Bartmann P, Cheong JLY, Doyle LW, Hack M, et al. Mathematical performance in childhood and early adult outcomes after very preterm birth: an individual participant data meta-analysis. Dev Med Child Neurol 2022;64:421-8.
54. Melhuish EC, Sylva K, Sammons P, Siraj-Blatchford I, Taggart B, Phan MB, et al. The early years. Preschool influences on mathematics achievement. Science 2008;321:1161-2.
55. Organisation for Economic Co-operation and Development (OECD). International early learning and child Wellbeing study - a summary of findings. 2020. Accessed May 6, 2022. https://www.oecd.org/education/school/early-learning-and-child-well-being-study/International_Early_Learning_and_Child_Well-being_Study_Summary.pdf
56. Treyvaud K, Doyle LW, Lee KJ, Ure A, Inder TE, Hunt RW, et al. Parenting behavior at 2 years predicts school-age performance at 7 years in very preterm children. J Child Psychol Psychiatry 2016;57:814-21.
57. Wolke D, Jaekel J, Hall J, Baumann N. Effects of sensitive parenting on the academic resilience of very preterm and very low birth weight adolescents. J Adolesc Health 2013;53:642-7.
58. Neel MLM, Stark AR, Maitre NL. Parenting style impacts cognitive and behavioural outcomes of former preterm infants: a systematic review. Child Care Health Dev 2018;44:507-15.
59. Breslau N, Paneth NS, Lucia VC. The lingering academic deficits of low birth weight children. Pediatrics 2004;114:1035-40.
60. van Houdt CA, van Wassenaer-Leemhuis AG, Oosterlaan J, van Kaam AH, Aarnoudse-Moens CSH. Developmental outcomes of very preterm children with high parental education level. Early Hum Dev 2019;133:11-7.
61. Davis-Kean PE. The influence of parent education and family income on child achievement: the indirect role of parental expectations and the home environment. J Fam Psychol 2005;19:294-304.

62. Han J, Cui N, Lyu P, Li Y. Early-life home environment and child cognitive function: a meta-analysis. Pers Individ Dif 2023;200:111905.
63. Organisation for Economic Co-operation and Development (OECD). Learning for tomorrow's world. First Results from PISA 2003. OECD. Paris, France: Programme for International Student Assessment; 2004.
64. Melhuish EC, Phan MB, Sylva K, Sammons P, Siraj-Blatchford I, Taggart B. Effects of the home learning environment and preschool center experience upon literacy and numeracy development in early primary school. J Soc Issues 2008;64:95-114.
65. Marlow N, Ni Y, Lancaster R, Suonpera E, Bernardi M, Fahy A, et al. No change in neurodevelopment at 11 years after extremely preterm birth. Arch Dis Child Fetal Neonatal 2021;106:418-24.
66. Burnett AC, Anderson PJ, Lee KJ, Roberts G, Doyle LW, Cheong JLY. Trends in executive functioning in extremely preterm children across 3 birth eras. Pediatrics 2018;141:e20171958.